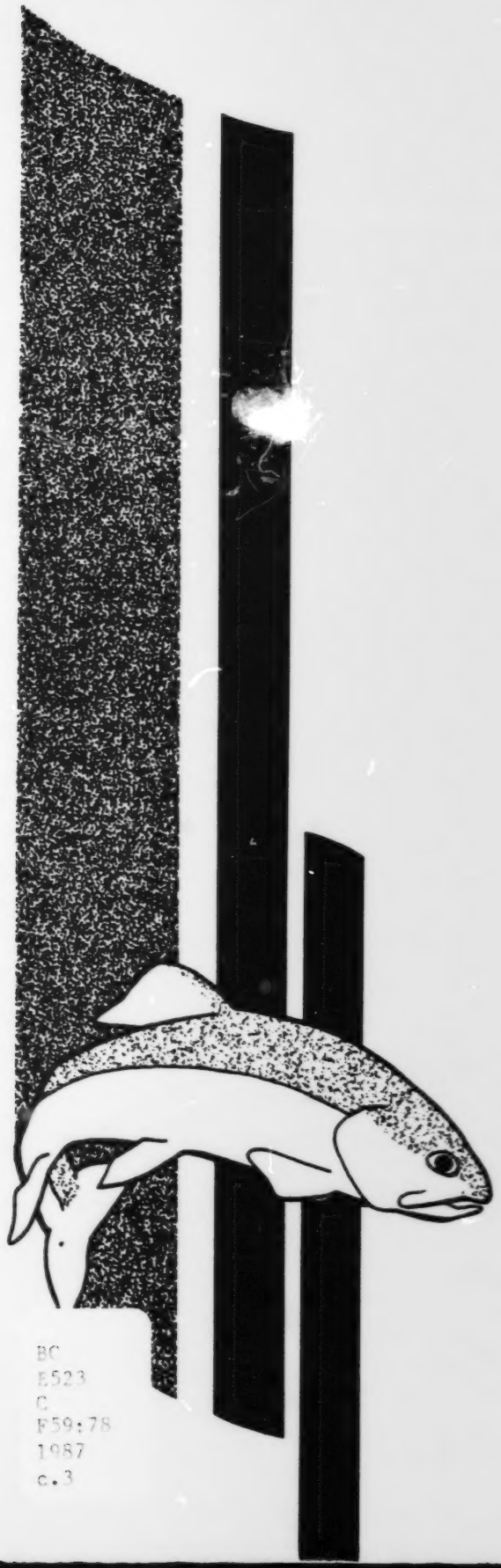

Artificial Circulation in British Columbia: Review and Evaluation

by

KENNETH I. ASHLEY

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ARTIFICIAL CIRCULATION IN BRITISH COLUMBIA: REVIEW AND EVALUATION

by

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ABSTRACT

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Artificial circulation in British Columbia started at Corbett Lake in the early 1960's and progressed through an experimental period at Yellow Lake (1976-1979) before developing into a full scale program in the 1980's. A review of twenty-three circulation projects identified site selection (infrequent winterkill), equipment (hose kinking, diffusor design, compressor and blower breakdown), operation (maintenance and seasonal scheduling) and evaluation (oxygen concentrations, fish survival and angler response) as the most common problem areas. Benefit-cost analysis was used to assist in evaluating the cost effectiveness of artificial circulation. The average benefit-cost of a sub-sample of 10 Kamloops area artificial circulation projects was 3.5 for electric units and 2.4 for diesel units under ideal conditions. Actual benefit-cost ratios may be lower due to infrequent winterkill and equipment and operational problems. The principal conclusion from the benefit-cost analysis is that site selection is the most important factor influencing the potential cost effectiveness of an artificial circulation project. Future research possibilities are outlined in the fields of physical, chemical and biological limnology and engineering. Nine recommendations are given ranging from maintenance suggestions to the use of a standard benefit-cost model to initially evaluate future artificial circulation proposals.

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INTRODUCTION

Artificial circulation has become an important management technique in British Columbia for improving over-winter trout survival in interior winterkill lakes and providing adequate summer refugia in eutrophic coastal lakes. Since 1976, circulation systems have been installed in 23 lakes ranging in size from 3.2 ha to 195 ha with a total combined surface area of 754 ha (Table 1). The technology utilized to circulate these lakes has been quite innovative, ranging from fractional kilowatt solar and wind powered units to large scale (37 kW) electric compressors and diesel blowers.

Artificial circulation in British Columbia is now at a turning point. Most of the easily accessible lakes are being circulated and future projects will require considerable expenditures of capital and labour. A thorough review of existing projects is required to ensure that appropriate technologies are being utilized, and the cost effectiveness is favorable and comparable to alternate lake enhancement strategies, e.g., chemical rehabilitation (Griffith 1982).

The purpose of this paper is fourfold:

1. Document the historical development of artificial circulation in British Columbia.

2. Review the individual projects and examine common problem areas.

3. Provide a benefit-cost analysis on a sub-sample of 10 lakes.

4. Provide recommendations on future research and application of artificial circulation in British Columbia.

HISTORY OF ARTIFICIAL CIRCULATION IN B.C.

The consequences of low summer and winter oxygen concentrations on trout survival in shallow, productive lakes has been known for many years. Larkin (1954) first mentioned this problem in relation to British Columbia's interior lakes and stated "their future improvement and management poses a challenging problem to the fish culturist". In B.C. a province wide survey of 100 lakes (Northcote and Larkin 1956) confirmed the vast majority of small lakes in the southern interior plateau region exhibited marked hypolimnetic oxygen depletion during summer months and severe whole-lake oxygen depletion during winter months. Meanwhile, various fisheries management agencies began reporting on the use of compressed air injection to induce artificial circulation and improve over-winter survival of trout (Schmitz and Hasler 1958; Rassmussen 1960; Patriarche 1961). In British Columbia, artificial circulation was quickly recognized as a possible management technique for preventing winterkill of trout.

Table 1. Summary of regional artificial circulation installations.

Lake		Type	Size (kW)	Output (m^3 min^{-1})	Power	Circulation
			Region 1			
Glen	(1985)	Compressor	2x3.7	2x0.57	220V-1ø	Hypolimnetic
Langford	(1984)	Compressor	2x5.6	2x0.79	220V-1ø	Destrat.
St. Mary	(1985)	Compressor	37.0	7.1	440V-3ø	Hypolimnetic
			Region 2			
Serpentine	(1985)	Blower	2x3.7	2x1.7	220V-1ø	Destrat.
			Region 3			
Bleeker	(1981)	Compressor	2x5.6	2x0.79	220V-1ø	Destrat.
Corbett	(1983)	Compressor	2.2	0.39	220V-1ø	Destrat.
Edith	(1982)	Compressor	22.4	2.0	Diesel	Destrat.
Frisken	(1984)	Compressor	22.4	2.0	Diesel	Destrat.
Lodgepole	(1981)	Compressor	3.7	0.57	220V-1ø	Destrat.
Logan	(1982)	Compressor	5.6	0.79	220V-1ø	Destrat.
Menzies	(1986)	Surface Aerator	0.75		220V-1ø	Destrat.
Rose	(1981-84)	Compressor	2.2	0.39	220V-1ø	Destrat.
	(1985-86)	Surface Aerator	0.25		220V-1ø	Destrat.
Tulip	(1981-84)	Compressor	5.6	0.79	220V-1ø	Destrat.
	(1985-86)	Surface Aerator	0.25		220V-1ø	Destrat.
Walloper	(1981)	Compressor	5.6	0.79	220V-1ø	Destrat.
			Region 4			
Ha-Has	(1984)	Blower	20.1	7.1	Diesel	Destrat.
Johnson	(1985)	Blower	5.6	1.7	220V-1ø	Destrat.
Solar	(1987)	Submersible Pump	0.75		Solar	Destrat.
			Region 5			
Buckskin	(1983)	Compressor	22.4	2.0	Diesel	Destrat.
Skulow	(1982)	Compressor	5.6	0.79	220V-1ø	Destrat.
			Region 7			
Beaver	(1986)	Blower	18.6	1.7	Propane	Destrat.
Inga	(1984)	Surface Aerator			Wind	Destrat.
			Region 8			
Gardom	(1979)	Compressor	2x5.6	2x0.79	220V-1ø	Destrat.
Yellow	(1976)	Compressor	11.2	1.9	440V-3ø	Destrat.
Yellow Pothole	(1977)	Compressor	7.5	1.1	440V-3ø	Hypolimnetic

Initial Experiments (1961-1975)

In 1961 the first artificial circulation project in British Columbia was initiated at Corbett Lake (near Merritt). This was an important study as it identified incomplete autumnal circulation as a causative factor in winterkill, outlined the importance of local topography and prevailing wind direction on lake circulation and demonstrated that artificial circulation could provide sufficient oxygen to prevent over-winter fish mortality (Halsey 1968). Further research at Corbett Lake in 1964 involved improving the efficiency of the circulation system, and a single point-release diffusor was found to be more effective than a line-release system (Halsey and Galbraith 1971).

Yellow Lake (near Kaleden) was B. C.'s second artificial circulation project. Yellow Lake had been identified during an earlier survey (1961-62) of several lakes which were marginal for rainbow trout production (Northcote and Halsey 1969). Yellow Lake also experienced incomplete fall circulation due to its morphometry and local topography. A diesel powered circulation system was installed in Yellow Lake and operated from November 5 to December 21, 1969. Although artificial circulation initially lowered whole-lake oxygen concentrations and killed several thousand trout, oxygen concentrations eventually increased and allowed over-winter survival of stocked trout and char (Halsey and MacDonald 1971).

Despite these promising results, further application of artificial circulation was restricted by the lack of a suitable power source. The diesel compressors used at Corbett and Yellow lakes were high maintenance machines requiring daily attention. In 1970 a local Merritt resident proposed using wind energy to power artificial circulation systems. Heinz Lange built at least seven wind powered circulation systems between 1970 and 1975, and installed them throughout the southern interior region (Centre, Corbett and Edna lakes - Merritt; Black, Bleeker and Walloper lakes - Kamloops; Yellow Lake - Kaleden) (Shewchuck 1975).

Although the windmills appeared impressive, they were generally ineffective at preventing winterkill due to a series of design faults. The windmills were built without governors so that high winds caused the units to seize or disintegrate and the units were fixed in one direction and unable to take advantage of the variable wind directions often encountered on winterkill lakes (e.g., Halsey 1968).

Yellow Lake Experimental Period (1976 - 1979)

Although both wind and diesel powered circulation systems were intermittently operated at Yellow Lake from 1970 - 1975, it was apparent that neither system was suitable for long term use. As a result, an 11 kW electric compressor was purchased in 1976 in an attempt to reduce operating and

maintenance costs. In 1977 Yellow Lake Pothole, immediately adjacent to Yellow Lake, was chosen as a test site for Canada's first experimental hypolimnetic aeration system (Ashley 1981). This system was powered by a 7.5 kW electric compressor and operated continuously for 329 days. This system significantly improved the water quality of Yellow Lake Pothole and demonstrated the reliability of electric powered circulation (Ashley 1983). The conclusions from the Yellow Lake and Yellow Lake Pothole experiments were that long term, low maintenance artificial circulation was possible using electric power, and the cost appeared reasonable in relation to improved fish survival and water quality.

Full Scale Application (1979 - 1986)

In September 1979 a sampling program was initiated by the Fisheries Research Section to examine the seasonal limnology of winterkill lakes and collect background data on lakes which may be artifically circulated in future years. The program focused on several known winterkill lakes in the Kamloops area (Black, Bleeker, Edith, Frisken, Gardom, Horseshoe and Walloper).

The sampling program indicated low oxygen concentrations in Gardom Lake (near Salmon Arm) were a result of incomplete circulation and a slight degree of chemical stratification. In November 1979 a decision was made to install a circulation system on Gardom Lake based on its past winterkill history, known fish production capability, availability of electric power, and land for a compressor shed. Installation started in November 1979 and was completed in December 1980 following a series of delays involving electrical contracting, power line installation and equipment delivery.

In 1981, following the artificial circulation of Gardom Lake, two unrelated events occurred which significantly influenced the direction of artificial circulation in B. C. Firstly, an electric power line was installed along the Roche Lake road. This placed electric power within reasonable distance of several Kamloops area lakes (e.g., Black, Bleeker, Horseshoe, Rose, Tulip). Secondly, increased funding was made available through the establishment of the Habitat Conservation Fund (HCF) and the Inland Fisheries Enhancement Program (IFEP). As a result, five artificial circulation projects were initiated in the Kamloops region in 1981. The success of the Kamloops regional projects prompted other regions to initiate their own projects, and 2 - 4 artificial circulation systems have been completed each year since 1982 (Table 1).

In 1983 it became apparent that operation and maintenance costs were consuming an increasing share of artificial circulation project costs. In 1984 a decision was made to examine lower maintenance technologies for artificial circulation. This included the substitution of low pressure

blowers for compressors (Ha-Has, Johnson), propane for diesel fuel (Beaver), and an initial examination of wind power (Inga). Electric surface aerators were installed in three lakes (Rose, Tulip and Menzies) and a solar powered circulation system was developed and tested at Menzies Lake (Ward, Ashley and Dunford, 1986).

REVIEW OF PROBLEM AREAS

A large number of artificial circulation systems were installed between 1981 and 1984 (Table 1). Although the principle of artificial circulation was well understood at this time, the realities of a large scale installation and operation program were not. As a result, some projects have been more trouble free than others. The purpose of this section is to review the common problem areas and provide suggestions for their improvement.

Site Selection

Site selection problems were encountered in a few projects, the most common being the installation of circulation systems in non-winterkill lakes, or lakes in which the water chemistry was inherently toxic to fish.

The solution to these problems is collection of sufficient background data (minimum one year) including water chemistry, dissolved oxygen, temperature and live cage/experimental stocking of trout. This is the minimum amount of basic information required to effectively evaluate an artificial circulation proposal. If mid-winter oxygen concentrations do not approach near lethal concentrations for trout (approx. 2 mg/l), the lake's winterkill status should be re-evaluated and another year of sampling undertaken.

Equipment

Hose kinking has occurred at several installations, and results from the diffusor swinging about during operation causing the airline to fold over on itself. This problem can be solved by minimizing the amount of excess airline present and installing a 360° hydraulic hose swivel and short length (5 - 10 m) of hydraulic or wire-supported hose at the diffusor.

The steel cross-pipe diffusors used at the hypolimnetic aeration installations (Glen, St. Mary, Yellow Lake Pothole) are inadequate in terms of oxygen transfer efficiency, ranging from 6% at Yellow Lake Pothole to 18% at Glen Lake. These are significantly below the 25 - 50% efficiencies recorded at a number of installations (Lorenzen and Fast 1977). Considerable savings in capital and operating costs could be realized by

designing a diffusor with smaller pore sizes to increase oxygen transfer efficiency.

The diffusor design used in destratification systems has been trouble-free. An "Atara" style mixer is being tested at Langford Lake (near Victoria). This design employs a venturi principle which may be more efficient than the steel cross-pipe diffusors, however, until further testing is completed the standard diffusors are sufficient.

A serious equipment problem is the combination of a diesel engine directly driving a rotary blower. The engine vibrations disrupts the blower tolerances and blower breakdown usually occurs. This equipment combination should be avoided, however if a diesel engine and rotary blower are required they should be mounted separately on a concrete base and V-belt driven to isolate vibrations.

The Hydrovane compressors used in the majority of installations have been relatively trouble-free. Several compressors have experienced mechanical problems, however these can usually be traced to factory defects or improper installation (eg. Logan Lake). Warranty difficulties can arise when significant delays exist between compressor delivery date and actual start-up date as factory warranties start on the delivery date. If several months are expected to lapse between delivery and start-up date, the warranty should be revised to reflect this fact.

Operation

The seasonal scheduling of artificial circulation is critical to its success. For example, Corbett Lake (near Merritt) experiences incomplete fall circulation as indicated by annual oxygen-temperature profiles, and four to six weeks of fall artificial circulation is sufficient to prevent winterkill (Halsey 1968). In contrast, Edith Lake (near Kamloops) is an example of a winterkill lake which experiences complete spring and fall circulation, and is nearly saturated with oxygen prior to freeze-up. However, due to its eutrophic status, oxygen is rapidly consumed and optimal timing for artificial circulation is 4 - 6 weeks operation starting in early January. Fall circulation (natural or artificial) is often insufficient to prevent winterkill, and each lake must have the system's operation tailored to its individual characteristics.

Some lakes may require more than one period of artificial circulation per winter. An example would be a eutrophic lake which experiences incomplete fall circulation. Three to four weeks of artificial circulation may be required in October followed by another 3 - 4 weeks circulation in February. The critical stage of this operational strategy is when to re-start the circulation period in February. If the whole-lake

oxygen concentration decreases below approximately 3 mg/l, the start-up may cause a fish kill by initially depressing oxygen concentrations. The solution to these problems is sufficient data collection beforehand (one year minimum) to categorize the lakes' annual oxygen cycle, and regular monitoring during operation to ensure oxygen concentrations remain above critical concentrations.

Maintenance problems have occurred at a number of installations, and are largely a result of their isolated locations. The electric and diesel compressors used at most installations are complex machines designed for industrial use with regular maintenance. The isolated operation of these machines stretches the limits of their reliability and presents little opportunity to detect mechanical problems at an early stage. The best action is to equip the machines with fail-safe switches (i.e., low oil level, high oil temperature) and provide regular maintenance at the manufacturers' recommended intervals.

Maintenance has traditionally been carried out by Fisheries Branch staff. This may create problems as it assumes staff are completely familiar with the equipment, and able to provide service at the specified intervals. This is not always possible and the maintenance duties should be contracted out to qualified industrial mechanics. This would ensure qualified maintenance at regular intervals and eliminate such minor problems as using summer grade lubrication and fuel oils during winter.

Another approach is to use less complicated types of circulation equipment. This topic will be addressed in the benefit-cost analysis, however, a relative ranking in terms of decreasing mechanical complexity and maintenance costs is:

Diesel/Propane compressor	-	1	Highest
Diesel/Propane blower	-	2	
Electric compressor	-	3	
Electric blower	-	4	
Electric surface aerator	-	5	
Solar Powered circulator	-	6	
Wind Powered circulator	-	7	Lowest

A minor operational problem is the displacement of diffusor support rafts and air line during spring ice-off. This can be avoided by operating the circulation system for a few days at break-up to free support rafts from the ice sheet, and allow drifting ice to slide over the raft.

Evaluation

One of the biggest shortcomings of artificial circulation has been inadequate evaluation of its effects on the fishery. Although many studies have demonstrated its effect on oxygen concentrations and water chemistry, few have focused on changes in fish survival and angler effort which should follow successful circulation.

Evaluating the effectiveness of an artificial circulation project is relatively straightforward and involves three levels of evaluation. The first level involves measuring oxygen concentrations at regular intervals throughout the winter. Whole-lake average oxygen concentrations of 3 mg/l or greater throughout winter indicate a successful artificial circulation project. Average oxygen concentrations of 2 mg/l are borderline for trout survival and oxygen concentrations below 1 mg/l should result in fish kills (e.g., Shepard, 1955).

The second level of evaluation involves confirming winter fish survival the following spring via gill net sampling. The presence of one or more year classes of trout indicate a successful period of winter circulation.

The third level of evaluation requires some estimate of angler effort before and after the project is implemented. The amount and cost of data collection required to detect a given change in a fishing quality index (i.e., effort, CPUE, fish lengths, fish age) has not been well known. However, Parkinson et al. (in press) have recently examined this topic and concluded the cost of data acquisition appears reasonable even on very small lakes. In the case of artificially circulating a winterkill lake which did not support fish prior to circulation, the change in effort should be so obvious that relatively few samples would be required to detect this change. If the effort data was collected as part of a larger aerial survey of 20 lakes, a 50% change in effort could be detected at a cost per lake of approximately $800 spread over 4 - 8 years.

The first two levels of evaluation are the minimum amount of information required to determine if the project was successful. The third level (angler response) is necessary to determine the cost effectiveness of this type of project. The Ha-Has Lake report (Oliver 1987) is a good example of a three level evaluation of an artificial circulation project.

In the initial years of HCF support (i.e., 1981) evaluations were not considered priority components of project submissions. However, this policy changed in later years and evaluations are now considered legitimate proposals, whether independently or as part of larger project submissions (C. Wightman, pers. comm.). At present, HCF policy requires annual progress reports during the life of the project. This policy should be expanded to include a detailed evaluation of a

representative project within each general project grouping (e.g., stream clearance, lake rehabilitation, artificial circulation). This would indicate the general cost effectiveness of each type of project, and could be used as a reference for preliminary evaluation of future project submissions of a similar type.

BENEFIT-COST ANALYSIS

Benefit-cost analysis was used to assist in evaluating the cost effectiveness of artificial circulation. This technique provides a relative (rather than absolute) ranking of project value, and it fulfills a useful role in the evaluation process. Benefit-cost analysis has been used to evaluate several Fisheries Branch programs including trout stocking (Nordstrom et al. 1978); chemical lake rehabilitation (Griffith 1982) and inland enhancement (Reid 1981).

The benefit-cost model was adapted from Griffith (1982) and run on a Magicalc spreadsheet program. The analysis was conducted on a sub-sample of ten projects in the Kamloops area. These projects were located in the same geographic area, installed within a few years of each other, maintained by the same personnel and a detailed expense record existed for each lake.

Several assumptions were required for the model as insufficient data was available for some input variables. Each project was analysed using several fixed and site-specific variables. The fixed variables were: (1982 CDN dollars)

a. labour cost - $13/hr
b. period of operation - 90 days
c. cost of stocking yearling rainbow trout - $0.30 each
d. survival of stocked trout to catchable size - 50%
e. catchability of stocked trout - 60%
f. number of trout caught per angler day - 2
g. value of an angler day - $20
h. discount rate - 10%/yr

The site-specific variables were:

a. size of compressor motor - kW
b. surface area of lake - ha
c. shoal (< 6 m) area of lake - ha
d. total dissolved solids - mg/l

The last three variables (b, c, d) are used in the trout stocking formula (Stringer et al. 1980) which is built into the program to determine stocking cost, numbers of yearlings and expected benefits from anglers. This part of the benefit-cost analysis is termed the "standard conditions" analysis.

Following the "standard conditions" analysis, a representative project was selected (Walloper Lake) and subjected to a "sensitivity analysis" in which one fixed or site-specific variable was varied by ± 50% while the remaining variables were held under standard conditions. The purpose of this analysis was to examine the sensitivity of the final benefit-cost ratio to variations in fixed and site-specific input variables. A complete example of the Walloper Lake "standard conditions" analysis is given in the Appendix.

Standard Conditions and Sensitivity Analysis

The results of this "standard conditions" analysis are presented in Table 2. Benefit-cost ratios range from 1.9 to 5.1 for electric installations (mean = 3.5) and 2.1 to 2.6 (mean = 2.4) for diesel powered installations. All of the benefit-cost ratios are positive, suggesting that artificial circulation is revenue generating if the conditions of the analysis are met, i.e., stocking at the stocking formula, 50% survival, 60% catchability, 2 fish/angler day catch success and a value of $20/angler day.

In reality, some of the projects listed in Table 2 are less than the calculated benefit-cost ratio. The reason being the benefit-cost model depicts the "best case" scenario for a particular lake, i.e., 100% winterkill each year prior to artificial circulation, no mechanical problems, immediate angler response and little fishing effort prior to circulation.

In some cases there is no doubt the project is successful (e.g., Corbett Lake) and the true benefit-cost should be fairly close to the calculated benefit-cost. However, in projects involving infrequent winterkill (e.g., Walloper), small size (e.g., Rose) or extensive mechanical problems (e.g., Logan) the true benefit-cost is undoubtedly lower than the calculated benefit-cost. In addition, the benefit-cost model does not address the question of whether artificial circulation creates "new" angler-days or merely redistributes the existing angler effort within a particular area.

The sensitivity analysis of the Walloper Lake project produced several interesting results. The benefit-cost for Walloper Lake was 4.9 under standard conditions (Table 2) and the effect of varying the discount rate is shown in Table 3. Benefit-cost ratios ranged from 5.2 at 6% to 4.5 at 16% indicating the benefit-cost ratio is robust and relatively independent of discount rates.

Table 2. "Standard Conditions": Benefit-cost ratio for 10 Kamloops area artificial circulation projects.

Lake	Type	Benefit-Cost Ratio
Bleeker	Electric	3.0
Corbett	Electric	4.7
Gardom	Electric	5.1
Lodgepole	Electric	2.6
Logan	Electric	2.5
Rose	Electric	1.9
Tulip	Electric	3.4
Walloper	Electric	4.9
		mean = 3.5
Edith	Diesel	2.1
Frisken	Diesel	2.6
		mean = 2.4

Table 3. "Sensitivity Analysis": Effect of varying discount rate on Walloper Lake benefit-cost ratio.

Discount Rate (%)	Benefit-Cost Ratio
6	5.2
8	5.1
10	4.9
12	4.8
14	4.7
16	4.5

The sensitivity analysis indicates that varying the four main fixed input variables controlling the benefits from stocking (i.e., survival, catchability, fish/angler day, and value/angler day) results in equivalent changes in benefit-cost ratios. For example, a 50% increase in catchability results in a 50% increase in the benefit-cost ratio (Table 4). These results were not unexpected, and arise from the delayed entry (i.e., year 4) of the benefits into the benefit-cost analysis stream having already experienced 3 years of discounting at the prevailing rate (Appendix). Consequently, it is easy to visualize the result of varying these four input variables as they are matched by equivalent changes in benefit-cost.

Table 4. "Sensitivity Analysis": Effect of varying catchability on Walloper Lake benefit-cost ratio.

Catchability (%)	Benefit-Cost Ratio
15	1.2
30	2.5
45	3.7
60	4.9
75	6.2
90	7.4

The benefit-cost ratio was relatively insensitive to changes in labour cost, period of operation and motor size as ± 50% variations influenced the benefit-cost ratio by 0.5 or less. In addition, the benefit-cost ratio was insensitive to ± 50% change in electrical supply cost ($/kWh) and initial survey costs.

Although individual operation and maintenance costs have little effect on benefit-cost ratios, their cumulative effects consume significant amounts of regional budgets. Therefore, to optimize artificial circulation, the system should operate as little as possible to minimize operation and maintenance costs, but long enough to prevent winterkill. A "lake aeration strategy table" has been developed to address this problem and is currently under review (Ashley, unpubl.). The key piece of information required for optimal operation is regular (i.e., every two weeks) oxygen-temperature data collection. This represents a minimal cost in terms of actual budgets and effect on benefit-cost ratios, and is necessary to ensure efficient operation.

The only operations and maintenance cost that significantly influenced the benefit-cost ratio was the cost of stocking yearlings (Table 5). Stocking costs start at year three in the time schedule and continue yearly at the prevailing discount rate (Appendix). This implies that increases in stocking costs could adversely affect the benefit-cost ratio without coincident increases in survival, catchability and value/angler day, and that decreases in stocking costs could improve the benefit-cost ratio.

Table 5. "Sensitivity Analysis": Effect of varying stocking costs on Walloper Lake benefit-cost ratio.

Cost per Yearling	Benefit-Cost Ratio
$0.10	8.2
$0.20	6.2
$0.30	4.9
$0.40	4.1
$0.50	3.5
$0.60	3.1

Validity of the Benefit-Cost Model

Three different approaches were used to examine the validity of the benefit-cost model. The first approach involved comparison with an independent benefit-cost analysis of seven Kamloops area artificial circulation projects. This analysis (Reid 1981) produced an average benefit-cost ratio of 3.3 (@ 10% discount rate) which is consistent with this report. No other published reports of artificial circulation benefit-cost analysis were located.

The second approach involved comparing the angler effort predicted from the model with estimates of angler effort obtained from regional aerial surveys. The results (Table 6) indicate the range of predicted effort (angler-days/yr/ha) is within the range of effort recorded at several southern interior plateau lakes.

The third approach involved recalculating the benefit-cost ratio to a break-even point and examining how many anglers would be required to achieve a 1:1 benefit-cost ratio. The results (Table 7) indicate a range of 229 to 1100 angler days/year would be required to achieve a 1:1 benefit-cost ratio.

The purpose of this approach was to determine if the angler-days/year/hectare at the breakeven point (i.e., 1:1) were distinctly lower than the angler-day/yr/ha obtained from the

Table 6. Comparison of angler effort predicted from B/C model to Katimavik Survey data from Okanagan area lakes.

Predicted effort from benefit-cost model:

Lake	B/C	Area (ha)	Angler-days/year	Angler-days/year/ha
Bleeker	3.0	35.6	3016	85
Corbett	4.7	24.2	1922	79
Gardom	5.1	72.8	5107	70
Lodgepole	2.6	6.8	750	110
Logan	2.5	11.5	746	65
Rose	1.9	3.2	435	136
Tulip	3.4	10.1	1371	136
Walloper	4.9	36.4	3053	84
Edith (diesel)	2.1	25.1	2115	84
Frisken (diesel)	2.6	28.7	2860	100

Actual effort from Katimavik Survey:

Lake	Area	Angler-days/year	Angler-days/year/ha
Headwater #1	58.4	2417	41
Lady King	6.2	1695	273
Pianus	165.6	7900	48
Posthill	93.0	1725	19
Jacko	34.4	7500	218

Table 7. Estimation of angler effort required to break-even (1:1) on benefit-cost ratio.

Lake	1:1 Angler-days/year	1:1 Angler-days/year/ha
Bleeker	1005	28
Corbett	409	17
Gardom	1001	14
Lodgepole	288	42
Logan	298	26
Rose	229	72
Tulip	403	40
Walloper	623	17
Edith	1007	40
Frisken	1100	38

regional aerial surveys. For comparative purposes, an average instantaneous boat count of 1 is equivalent to approximately 1000 angler days/year (assuming 12 boat hrs/day, 2 people/boat, 4 hrs/angler day and 170 day fishing season) (E. Parkinson, pers. comm.).

These results suggest the benefit-cost model is reasonably accurate in predicting angler effort. Site-specific variables outside the model's input will shift these estimates up (e.g., a resort on the lake) or down (e.g., 50 km of rough road) depending on the circumstances. The final benefit-cost ratio should be adequate for management purposes assuming the remainder of the model's main assumptions are correct.

Economy of Scale, Frequency of Winterkill and Power Line Costs

Three factors known to influence the cost effectiveness of artificial circulation are economy of scale, frequency of winterkill and power line costs. Economy of scale occurs when unit costs decrease with increasing scale of operation. Most industrial processes benefit from economy of scale and artificial circulation is no exception. The total cost (discounted over ten years at 10%) of artificial circulation increases with lake size (Fig. 1). However, total costs per hectare decreases (Fig. 2) indicating a significant economy of scale. This is a result of several factors including fixed costs independent of lake size (e.g., compressor shed, electrical contracting) and economy of scale in purchasing equipment (e.g., compressors, air line). In terms of future artificial circulation projects, these results suggest the following:

Large Lakes (> 100 ha)

Although the actual costs are high, the economy of scale indicates large lake circulation may be cost effective. In reality, few large lakes in British Columbia will require artificial circulation since lake depth generally increases with surface area thus decreasing the winterkill risk. However, in the few cases where a large shallow lake winterkills, artificial circulation could be a cost effective solution.

Small Lakes (< 100 ha)

Artificial circulation of small lakes is less expensive in total costs, however more expensive per unit area than large lakes. This relationship increases sharply at 10 ha (Fig. 2) therefore lakes < 10 ha should not be artificially circulated unless they are extremely productive, will generate a quality fishery, and no other suitable lakes are located in the area. The relationship in Fig. 2 is based on conventional electric/diesel powered compressor type of artificial circulation. The sharp increase in cost/ha at 10 ha indicates

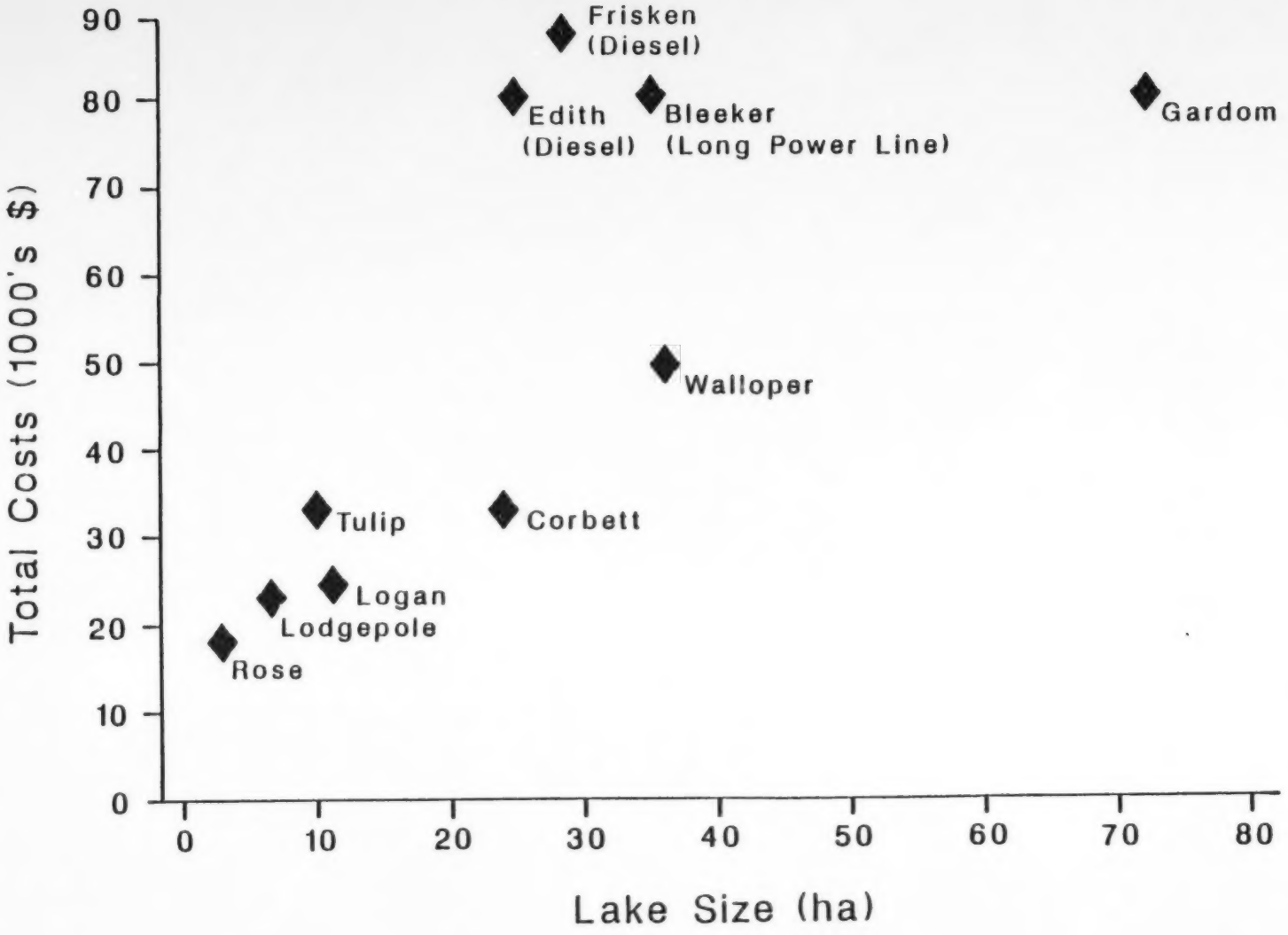

Fig. 1. Total cost of artificial circulation vs lake size.

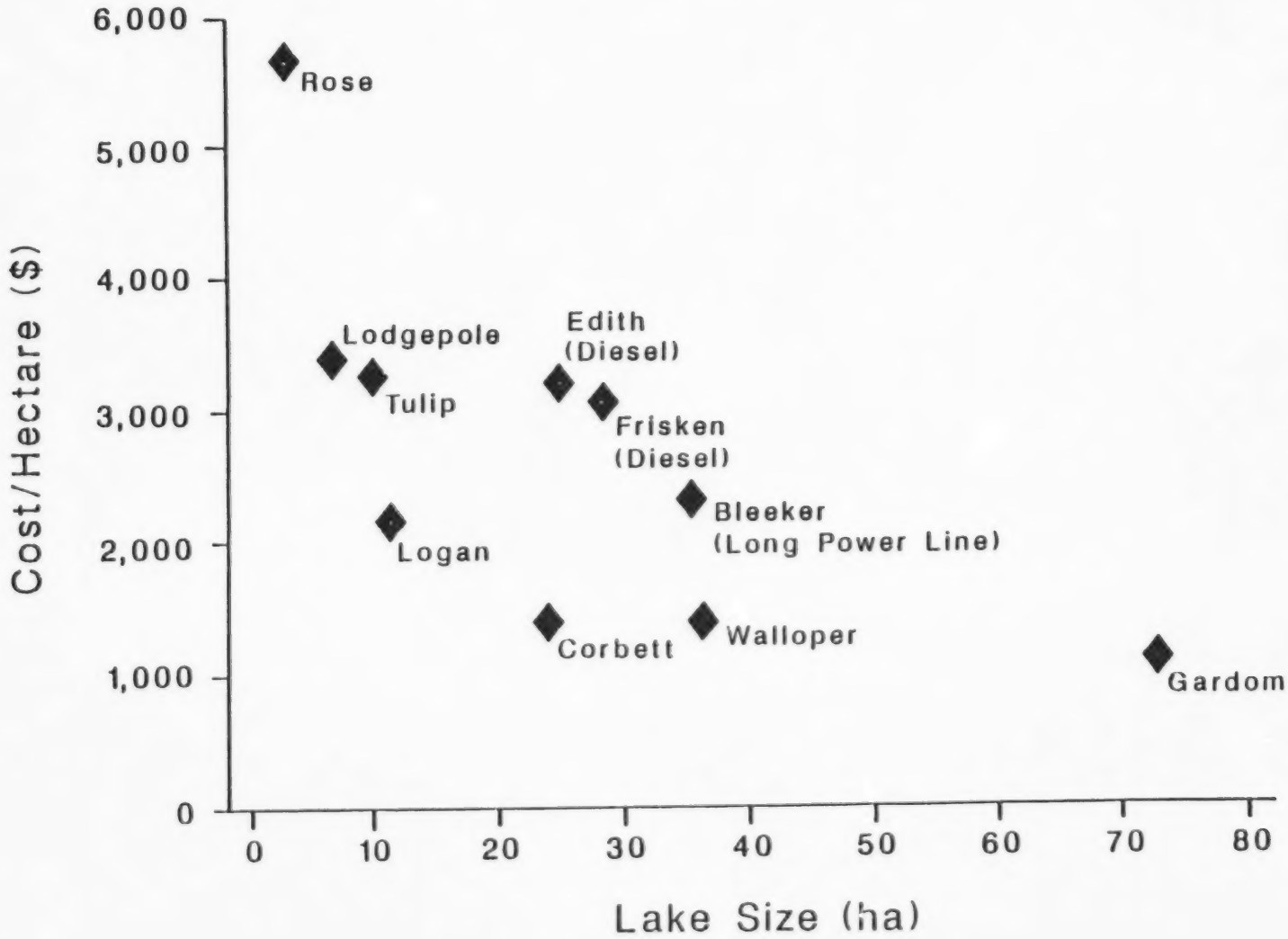

Fig. 2. Cost/hectare of artificial circulation vs lake size.

this type of circulation technology is not cost effective on lakes < 10 ha. Therefore less expensive equipment should be used to circulate lakes < 10 ha. Solar powered and surface aerators (e.g., Air-o-lators) are the logical choice for these lakes. Internal combustion powered circulation (e.g., diesel and propane) should not be used on lakes under 10 ha except in special circumstances.

Frequency of Winterkill

The frequency of winterkill is one of the most important factors influencing the cost effectiveness of artificial circulation. This aspect of artificial circulation generally receives little attention prior to installation. The approach used to examine the effect of winterkill frequency was to progressively remove benefits from the final benefit-cost table (Appendix) to simulate the effect of non-winterkill years in which the benefits derived from angling could not be attributed to the artificial circulation system. The effect of removing non-winterkill benefits will also vary depending on which year they occurred in the 10 year discount schedule. Therefore a range of benefits was obtained representing removal of non-winterkill benefits from early and late in the program.

The results in Table 8 indicate the final benefit-cost ratio of Walloper Lake (4.9:1) is reduced to approximately 1:1 when a non-winterkill year occurs six out of every seven years, i.e., 14% winterkill risk)). An artificially circulated lake with a higher benefit-cost ratio could withstand more non-winterkill years and still break even (i.e., 1:1 benefit-cost) than a low benefit-cost ratio lake. However, it appears unlikely that few lakes could remain cost effective at a winterkill frequency less than 20% (i.e., winterkills one out of five years).

Table 8. Effect of frequency of winterkill on Walloper Lake benefit-cost ratio.

Frequency of Winterkill (yr)	B/C (early)	B/C (late)
7/7	4.9	4.9
4/7	2.6	3.4
3/7	1.9	2.7
2/7	1.2	1.9
1/7	0.6	1.0

Therefore, to properly evaluate the cost effectiveness of a proposed artificial circulation project, the frequency of

winterkill should be known before a system is installed. A lake does not have to winterkill every year to warrant a cost effective artificial circulation system, however enough background data should be present so that a model can be used to determine the benefit-cost ratio and examine the effect of non-winterkill years on the overall cost effectiveness of the proposed installation.

Power Line Costs

The cost of supplying electricity is the most important component influencing the feasibility of electrically powered artificial circulation systems. In situations where lakes are located relatively close to power lines (< 200 m), the cost of supplying electricity is reasonable and similar to many of the component costs of the circulation system (e.g., $1000 - 2000). However, when power line distances approach 1 km the costs increase sharply and significantly influence the cost effectiveness of the system. Current (1986) power line installation costs are approximately $12,000/km for rural extensions on clear level ground. Installation costs are higher for wooded terrain or on steep slopes.

Walloper Lake was used as an example to demonstrate the length of power line required to reduce the benefit-cost ratio to the break-even point (1:1). As shown in Table 9, a power line length of 17 km reduces the benefit-cost from 4.9 to 1. Therefore realistic power line costs should be included in the benefit-cost model to accurately assess the cost effectiveness of a proposed circulation project.

Table 9. Effect of power line length on Walloper Lake benefit-cost ratio.

Power Line Length (km)	Discounted Cost ($)	B/C Ratio
0.2	2,002	4.9
0.5	5,460	4.5
1.0	10,920	4.1
2.0	21,840	3.4
4.0	43,680	2.6
8.0	87,360	1.8
16.0	174,720	1.1
17.0	185,640	1.0

Conclusions from Benefit-Cost Analysis

Several conclusions arise from the benefit-cost analysis. The general effect of the discounting procedure suggests that high costs in early years should be avoided, and that higher costs in later years are acceptable as they are

discounted to a large degree. This does not mean that diesel powered circulation systems should be favoured as the cumulative effect of several diesel powered systems soon develops into an expensive and time consuming program.

The best solution is to select circulation systems that have relatively low initial costs and low operation and maintenance costs. In terms of actual equipment, surface aerators (e.g., Air-o-lator), solar powered circulators and wind powered circulators would be the best choice for small lakes (< 10 ha), and electric compressors, blowers or surface aerators best suited for large (> 100 ha) lakes.

The overall conclusion that emerges from the benefit-cost analysis is that site selection is the most important factor influencing the cost effectiveness of a proposed artificial circulation project. The reasons for this conclusion are numerous:

a) The cost of site selection is low, both in real budgetary terms and its effect on final benefit-cost ratios.

b) Each lake must be examined individually due to the large number of variables influencing the cost effectiveness of a proposed project. Adequate site selection surveys will ensure that such variables as power line costs, frequency of winterkill and economy of scale are taken into consideration.

c) In reality, site selection is one of the few variables influencing the cost effectiveness of an artificial circulation project that regional fisheries biologists have any control over. Most of the important variables that strongly influence benefit-cost ratios are beyond the control of the regional biologist, e.g., value of an angler day, survival, catchability, and stocking costs. However by carefully selecting individual lakes the regional biologist can optimize the site selection procedure and create a cost effective circulation project.

FUTURE RESEARCH

Although considerable research effort has been directed towards artificial circulation, further investigation is required in several areas.

Physical Limnology

A more accurate method of sizing destratification equipment to individual lakes is required. Until now, most

destratification systems have been sized on the basis of published reports, past experience and good luck. However, a more quantitative approach is required similar to the procedure recently developed for sizing hypolimnetic aeration systems (Ashley 1985).

One approach would be to use the stability index to examine the efficiency of various destratification techniques. This approach has been used before (Symons et al. 1967) and should be re-examined. In addition, dye experiments could be used to trace the movement of circulation currents within the lake and improve our understanding of the hydrodynamics of destratification (e.g., Vanray 1969).

Chemical Limnology

Over the past few years, considerable attention has been directed at predicting rates of oxygen consumption in ice covered lakes (e.g., Babin and Prepas 1985; Mathias and Barica 1980; Jackson and Lasenby 1982). However, few studies have examined the effect of artificial circulation on winter oxygen consumption. The studies that have examined this topic (Ashley 1983; McQueen et al. 1984) discovered significantly higher rates of oxygen consumption during artificial circulation. The possibility exists that artificial circulation may induce long-term changes in lake metabolism and eventually increase oxygen consumption. The recent winterkills (winter 1985-86) of two lakes (Bleeker and Logan) despite several years continuous circulation lends some credibility to this hypothesis. This aspect of artificial circulation requires further research.

The concept of using artificial circulation in combination with other lake restoration techniques (e.g., rotenone, alum or lime applications) should be investigated. It may be possible to manipulate phytoplankton community structure by combining nitrogen addition and artificial circulation, thus favoring green algae and diatoms over blue-green algae (e.g., Barica et al. 1980). This could result in lower rates of organic deposition on the lake bottom, thereby decreasing oxygen demand and winterkill risk.

Nitrogen might also be removed from eutrophic lakes by alternating periods of hypolimnetic aeration and deoxygenation to effect a nitrification-denitrification sequence. This procedure is used in some biological nutrient removal sewage treatment plants (Paepcke 1985) and may result in significant nitrogen removal from lakes (Chen et al. 1979). Additional ideas on possible applications of hypolimnetic aeration are given in Ashley (1983).

Biological Limnology

The effect of artificial circulation on benthic invertebrates has received little attention. In theory, oxygenation of a previously anoxic hypolimnion should result in recolonization of benthic invertebrates. This effect was observed in a San Diego reservoir (Inland Fisheries Branch 1970) and it would be useful to know if the same response occurs in winterkill lakes. Large populations of benthic feeding bottom organisms, combined with sufficient oxygen concentrations, could significantly enhance chemical and biological degradation of organic detritus and ultimately reduce oxygen demands and winterkill risk while increasing the potential food supply for trout.

The long term effects of artificial circulation on lake productivity are not well known. The net result of several years circulation may be a decrease in productivity as the "barren lake" effect wears off, resulting in slower fish growth (Anderson 1972). The extent to which increased benthic food production would compensate for possible decreased productivity is unknown, however trout stocking rates may have to be adjusted downwards as the ecosystem becomes less productive. It may be beneficial to allow certain lakes to winterkill and remain fallow every few years to retain the high productivity characteristic of many southern interior plateau region lakes.

Engineering Studies

As discussed in the benefit-cost section, the desired trend in engineering design is towards artificial circulation equipment with lower operating and maintenance costs, i.e., solar power, wind power and surface aerators. The Fisheries Branch is already proceeding in this direction and this trend should continue, including an initial investigation of the Flygt 4410 Flowmaker. This is a large (prop. dia. = 1.8 m), low power ($\pm$10 kW) submersible mixer that generates large flows (3.4 $m^3 s^{-1}$). This mixer may allow artificial circulation of large lakes at well below conventional cost estimates.

In terms of hypolimnetic aeration, the standard design used by the Fisheries Branch is very good. However, this design has low oxygen transfer efficiencies (Ashley et al. 1987). The evidence suggests the diffusors are responsible as perforated pipe diffusors are generally less efficient at oxygen transfer than porous filter diffusors (Markofsky 1979). A modest increase in oxygen transfer efficiency could result in 50% reductions in compressor size and operating costs.

A variety of research experiments on hypolimnetic aeration remain to be done. For example, new low cost designs using plastic curtains are possible, and the effect of

hypolimnetic aeration on nitrogen gas saturation should be examined. However, these experiments will remain low priority until more hypolimnetic aeration installations are proposed for British Columbia.

RECOMMENDATIONS

1. Site selection is the most important aspect of artificial circulation and more emphasis should be placed on adequate (1 - 2 year) data collection prior to project submission.

2. Maintenance of artificial circulation equipment should be contracted out to qualified mechanics.

3. More emphasis should be placed on evaluating the effectiveness of artificial circulation by measuring mid-winter oxygen concentrations, fish survival and angler response.

4. A benefit-cost model should be used to initially evaluate artificial circulation project submissions, including the effects of frequency of winterkill, economy of scale and length of power line.

5. Artificial circulation of large lakes (> 100 ha) should not be discouraged because of total cost as economy of scale suggests the technique is cost effective.

6. Small lakes (< 10 ha) should only be circulated if they are extremely productive, will generate a quality fishery and no other suitable lakes are located in the immediate area.

7. Low cost, low maintenance circulation equipment (e.g., solar, wind and surface aerators) should be used on small (< 10 ha) lakes.

8. Further research is required to assess the effects of artificial circulation on physical, chemical and biological components of the lake ecosystem, and to develop more efficient and cost effective circulation technology.

9. The conclusion is that artificial circulation, if properly sited, operated and maintained, is a cost effective and useful technique for enhancing recreational fisheries.

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APPENDIX 1

LISTING OF ARTIFICIAL CIRCULATION INSTALLATIONS

The following is a brief technical summary of each artificial circulation system, including lake size, maximum depth, location, power source and installation date.

Region 1 - Vancouver Island

Glen Lake - 48°26'20"N, 123°31'15"W, near Victoria, B. C. 16.0 ha, mean depth = 7.2 m, installed in 1985. Hypolimnetic aeration system powered by two 3.7 kW rotary vane compressors (0.57 $m^3 min^{-1}$ each F.A.D. @ 7.0 kg cm^{-2}) operating on 220V single phase electricity

Langford Lake - 48°27'0"N, 123°31'45"W, near Victoria, B. C., 60.1 ha, mean depth = 8.5 m, installed in 1984. Destratification system powered by two 5.6 kW rotary vane compressors (0.79 $m^3 min^{-1}$ each F.A.D. @ 7.0 kg cm^{-2}) operating on 220V single phase electricity.

St. Mary Lake - 48°53'30"N, 123°32'15"W, on Saltspring Island, B. C., 195.0 ha, mean depth = 9.1 m installed in 1985-86. Hypolimnetic aeration system powered by a 37 kW rotary screw compressor (7.1 $m^3 min^{-1}$ F.A.D. @ 7.0 kg cm^{-2}) operating on 440V three phase electricity.

Region 2 - Lower Mainland

No installations on lakes, one instream installation on Serpentine River, near Surrey, B. C., max depth = 4 m, installed in 1985. Destratification system powered by two 3.7 kW rotary blowers (1.7 $m^3 min^{-1}$ each @ 0.7 kg cm^{-2}) operating on 220V single phase electricity.

Region 3 - Thompson-Nicola

Bleeker Lake - 50°30'0"N, 120°9'30"W, near Kamloops, B. C., 35.6 ha, mean depth = 7.9 m, installed in 1981-82. Destratification system powered by two 5.6 kW rotary vane compressors (0.79 $m^3 min^{-1}$ each F.A.D. @ 7.0 kg cm^{-2}) operating on 220V single phase electricity.

Corbett Lake - 50°1'30"N, 120°37'30"W, near Merritt, B. C., 24.2 ha, mean depth 6.9 m, installed in 1983. Destratification system powered by a 2.2 kW rotary vane compressor (0.39 $m^3 min^{-1}$ F.A.D. @ 7.0 kg cm^{-2}) operating on 220V single phase electricity.

Edith Lake - 50°34'15"N, 120°21'0"W, near Kamloops, B. C., 25.1 ha, mean depth 6.2 m, installed in 1982-83. Destratification system powered by a 22.4 kW rotary vane compressor (2.0 m^3 min^{-1} F.A.D. @ 7.0 kg cm^{-2}) operating on diesel fuel.

Frisken Lake - 50°27'30"N, 120°8'30"W, near Kamloops, B. C. 28.7 ha, mean depth = 4.9 m installed in 1984. Destratification system powered by a 22.4 kW rotary vane compressor (2.0 m^3 min^{-1} F.A.D. @ 7.0 kg cm^{-2}) operating on diesel fuel.

Lodgepole Lake - 50°31'0"N, 120°31'0"W, near Kamloops, B. C., 6.8 ha, mean depth = 3.6 m, installed in 1981. Destratification system powered by a 3.7 kW rotary vane compressor (0.57 m^3 min^{-1} F.A.D. @ 7.0 kg cm^{-2}) operating on 220V single phase electricity.

Logan Lake - 50°29'50"N, 120°48'0"W, near Logan Lake, B. C., 11.5 ha, mean depth = 3.5 m, installed in 1982. Destratification system powered by a 5.6 kW rotary vane compressor (0.79 m^3 min^{-1} F.A.D. @ 7.0 kg cm^{-2}) operating on 220V single phase electricity.

Menzies Lake - 50°0'45"N, 120°39'0"W, near Merritt, B. C., 3.7 ha, mean depth = 6.6 m, installed in 1986. Destratification system powered by a 0.75 kW surface aerator operating on 220V single phase electricity.

Rose Lake - 50°29'0"N, 120°10'0"W, near Kamloops, B. C., 3.2 ha, mean depth = 3.1 m, installed in 1981-82. Destratification system powered by a 2.2 kW rotary vane compressor (0.39 m^3 min^{-1} F.A.D. @ 7.0 kg cm^{-2}) operating on 220V single phase electricity. Retrofitted with a 0.25 kW surface aerator (110V, single phase) in 1985.

Tulip Lake - 50°29'0"N, 120°9'30"W, near Kamloops, B. C., 10.1 ha, mean depth = 3.2 m, installed in 1981-82. Destratification system powered by a 5.6 kW rotary vane compressor (0.79 m^3 min^{-1} F.A.D. @ 7.0 kg cm^{-2}) operating on 220V single phase electricity. Retrofitted with a 0.25 kW surface aerator in 1985.

Walloper Lake - 50°29'0"N, 120°32'0"W, near Kamloops, B. C., 36.4 ha, mean depth = 2.7 m, installed in 1981. Destratification system powered by a 5.6 kW rotary vane compressor (0.79 m^3 min^{-1} F.A.D. @ 7.0 kg cm^{-2}) operating on 220V single phase electricity.

Region 4 - Kootenay

Ha-Has Lake - 49°44'45"N, 115°49'20"W, near Kimberley, B. C. 42.9 ha, mean depth = 3.6 m, installed in 1984. Destratification system powered by a 20.1 kW rotary blower (7.1 m^3 min^{-1} @ 0.8 kg cm^{-2}) operating on diesel fuel.

Johnson Lake - 49°57'30"N, 115°45'45"W, near Kimberley, B. C. 12.1 ha, mean depth = 4.0 m, installed in 1985. Destratification system powered by a 5.6 kW rotary blower (1.7 m^3 min^{-1} @ 0.8 kg cm^{-2}) operating on 220V single phase electricity.

Solar Lake - 49°45'45"N, 115°49'20"W, near Kimberley, B. C. 5 ha, mean depth = 4.8 m, installed in 1987. Destratification system powered by a 0.75 kW submersible pump operating on 8 Arco M75 solar panels.

Region 5 - Cariboo

Buckskin Lake - 52°14'0"W, 122°18'0"W, near Williams Lake, B. C., 31.0 ha, mean depth = 6.4 m, installed in 1983. Destratification system powered by a 22.4 kW rotary vane compressor (2.0 m^3 min^{-1} F.A.D. @ 7.0 kg cm^{-2}) operating on diesel fuel.

Skulow Lake - 52°18'0"N, 122°55'0"W, near Williams Lake, B. C. 38.0 ha, mean depth = 2.0 m, installed in 1982-83. Destratification system powered by a 5.6 kW rotary vane compressor (0.79 m^3 min^{-1} F.A.D. @ 7.0 kg cm^{-2}) operating on 220V single phase electricity.

Region 6 - Skeena

No artificial circulation installations

Region 7 - Omineca-Peace

Beaver Lake - 58°58'N, 123°10'W, near Ft. Nelson, B. C., 6.9 ha, mean depth = 3.4 m, installed in 1986. Destratification system, powered by a 18.6 kW rotary blower (1.7 m^3 min^{-1} @ 0.8 kg cm^{-2}) operating on propane.

Inga Lake - 56°37'N, 121°38'W, near Ft. St. John, B. C., 54.2 ha, mean depth = 2.8 m, installed in 1984. Destratification system powered by a Series 1200 Lake-Aid wind powered floating circulator.

Region 8 - Okanagan

Gardom Lake - 50°36'20"N, 119°11'45"W, near Salmon Arm, B. C., 72.8 ha, mean depth = 9.3 m, installed in 1979-80. Destratification system powered by two 5.6 kW rotary vane compressors (0.79 $m^3 min^{-1}$ each F.A.D. @ 7.0 kg cm^{-2}) operating on 220V single phase electricity.

Yellow Lake - 49°20'15"N, 119°44'45"W, near Kaleden, B. C.,30.8 ha, mean depth = 17.4 m installed in 1976. Destratification system powered by a 11.2 kW rotary vane compressor (1.9 $m^3 min^{-1}$ F.A.D. @ 7.0 kg cm^{-2}) operating on 220/440V three phase electricity.

Yellow Lake Pothole - 49°20'30"N, 119°44'5"W, near Kaleden, B. C., 3.9 ha, mean depth = 4.5 m, installed in 1977-78. Hypolimnetic aeration system powered by a 7.5 kW rotary vane compressor (1.1 $m^3 min^{-1}$ F.A.D. @ 7.0 kg cm^{-2}) operating on 220/440V three phase electricity.

APPENDIX 2

STANDARD CONDITIONS BENEFIT-COST ANALYSIS FOR WALLOPER LAKE

Benefit-Cost variables for lake aeration:

Discount Rate	10%	TDS	128.0 mg/L
Labour Cost	13.0 $/hr	Yearling Cost	.30 $
Motor Size	5.6 kW	Survival	50%
Aeration Period	90.0 days	Catchability	60%
Surface Area	36.4 ha	Fish/Angler-Day	2.0
Shoal Area	32.5 ha	Value	20.0 $/A-D

	Water Chemistry			Labour				
	# of	$ per		# of	# of	$/hr		Total
Season	Samples	Sample	Cost	Trips	Hours	Labour	Cost	Cost
Spring	3	168	504	1	3	13	39	543
Summer	3	32	96	3	9	13	117	213
Winter	0	0	0	3	21	13	273	273
				Survey Total				1029

Evaluation of Survey Data:

Hours	$/hr Labour	Cost
7	13	91
Evaluation Total		91

Equipment Costs:

Part	Cost
Base	200
Shed	400
Compres	2800
Reg/Fil	130
ElecCon	1320
ServChg	10
PowerLi	2200
Hose	1175
Weights	100
Diffusor	100
Raft	100
Miscel	150
Equipment Total	8685

Installation Costs:

Hours	$/hr Labour	Cost
160	13	2080

Installation Total 2080

Operating Costs:

Motor	$/KWh	Period	Cost
5.6	.06	90	726

Electricity Total 726

Maintenance Costs:

Period	Trips	Hours	Labour	Cost
90	18	3	13	702

Maintenance Total 702

Replacement Costs:

Equipment	Factor	Cost
8685	.02	174

Replacement Parts 174

Stocking Costs:

Surface	Shoal	TDS	Fry	Yearlg	Cost	Total
36.4	32.5	128	203526	20353	.3	6106

Stocking Costs 6106

Benefits from Stocking:

Yearlg	Survl	Total	Catch-bility	Total	Fs/A-D	Value	Benefit
20353	.5	10176	.6	6106	2	20	61058

Total Benefits 61058

Time Frame for Costs and Benefits

Year	Spring	Summer	Fall	Winter	Total	Benefit
1	Survey 543	Survey 213	0	Survey 273	1029	0
2	Evalu 91	Constr 10765	0	Treat 1601	12457	0
3	Stock 6106	0	0	Treat 1601	7707	0
4	Stock 6106	0	0	Treat 1601	7707	61058
5	Stock 6106	0	0	Treat 1601	7707	61058
6	Stock 6106	0	0	Treat 1601	7707	61058
7	Stock 6106	0	0	Treat 1601	7707	61058
8	Stock 6106	0	0	Treat 1606	7707	61058
9	Stock 6106	0	0	Treat 1601	7707	61058
10	Stock 6106	0	0	Treat 1601	7707	61058

Final Benefit Cost Analysis

Year	PVF	Costs	Benefit
1	1.00	1,029	0
2	.91	11,325	0
3	.83	6,370	0
4	.75	5,791	45,874
5	.68	5,264	41,703
6	.62	4,786	37,912
7	.56	4,351	34,466
8	.51	3,955	31,332
9	.47	3,595	28,484
10	.42	3,269	25,894
		49,734	245,665

Total Discounted Costs	=	49,734
Total Discounted Benefits	=	245,665
B/C Ratio	=	4.94

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1986 89 Slaney, P.A. An Assessment of the Rainbow Trout (Salmo gairdneri) Population in the Upper Nechako River and the Effects of a Sportfishery Closure.